Mechanical Muscle

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A black rubber tube lay on the table of the robotics lab, looking strikingly out of place among the shiny oblong boxes of the motors and servos. It was something new, an oddity, the focus of much interest. "OK, I give up. What is it?" somebody asked.

"It's a pneumatic muscle," the director told him, "Inject air into it and it'll contract by two inches!"

"And…why exactly do we have it?"

"We just thought it was cool," the director answered, "We'll use it for something!"

In fact, artificial muscles are already used for many things—largely in the fields of robotics and prosthetics—and in the near future will be used for many more. One forthcoming technology is for victims of stroke, who are at risk of going blind when they lose control of muscles that actuate blinking. The muscles are tiny, but if they aren't working continually to wash the eye, it quickly looses moisture (Stuart, 2010). Currently, there are two treatments for this problem. In the first, a muscle is surgically removed from the leg and implanted in the face. This procedure is dangerous for the old or ill, and regardless of condition it's a six hour operation that inflicts a new wound. Alternatively, a small gold weight can be implanted in the eyelid, closing the lid with the help of gravity. The resulting blink is unsatisfactory in that it is out of sync with the normal eye and difficult to maintain when reclining. To improve upon these two choices, the newest option will be an artificial muscle implanted beneath the skin and controlled by a battery that takes input from the nerves of the good eye ("Ability to Blink", 2010).

Muscles are among the best understood structures in the body, but this has not always been true (Lieber, 2002). Renee Descartes in the 17th century was the first to realize that muscles don't change volume when they contract and that nerves are not in fact hollow tubes ("Muscles", 2009). Over a century later, Luigi Galvani used these deductions and experimentation with the legs of frogs to hypothesize that electricity is the force that motivates muscles. In fact, it is from this work involving stimulation to action that English takes the verb "galvanize" ("Luigi Galvani", n.d.). Still, it was not until the 1950s that muscle form and function were truly understood.

Natural muscles are optimized to produce force and motion. Fibers, the cells that compose them, differ substantially from basic cells in being extremely long (a muscle fiber from the thigh might measure a foot) and containing hundreds of nuclei (Martini, 1999). Inside the fibers are bundles of myofilaments, striated hexagonal filamentous proteins, which cause the bands of light and dark color on skeletal muscles.

Within the myofilaments is another level of filaments, called myofibrils. These do not stretch the entire length of the muscle fiber but rather are coupled together to form continuous

chains, which evidence suggests are arranged like the fibers in a rope. Myofibrils contain units called sarcomeres, joined end-to-end. Sarcomeres, the smallest contractile units of a muscle, shorten using thin and thick filaments (Lieber, 2002). The thick filaments look something like rods with double-threaded screws at both ends. The thin filaments are anchored to each end of the sarcomere, so when the thick filaments activate, pulling the thin towards the middle, the whole sarcomere contracts (Alberts et al., 2010). This action is multiplied by all the sarcomeres in a myofibril and all the myofibrils in a myofilament, before being transferred through the muscle fiber to the muscle itself.

Contracting is all a muscle can do. To return one to position after contraction, another muscle activates counter to the first. Mimicking this motion, an artificial muscle should contract when a charge is applied to it and relax—but not spring back into shape—when the charge is removed.

In the 1950s, the McKibben artificial muscle was developed for the benefit of polio victims. It consists of a rubber bladder under pressure from a wire mesh shell. When air is injected into the bladder, it expands radially, which forces the wire mesh to do the same. Because the strands of the mesh have a fixed length, when the device widens, it also shortens (Brabham et al., n.d.). These pneumatic muscles do not perfectly replicate the motions of a real muscle, but they are robust and lightweight and have been used for decades in robotics. Finding one in the lab of a high school robotics team, as I did this winter, would not be an uncommon occurrence for someone who frequents such places.

The Japanese have manufactured a mobile toy fish that carries no batteries or motor. It uses ionic polymer metal composites, another variety of artificial muscle developed in the 1990s. Their core is a layer of wet gel, sandwiched between two thin metal foils. When a different charge is applied to each foil, the ions in the gel migrate to one side and the whole sheet bends. The fish don't need their own power supply; they're activated from the top and bottom of the tank (Bar-Cohen, 2004). IPMCs don't actually contract the way real muscles do, but it's easy to see how their flexibility mimics the swimming motions of fish.

Carbon nanotubes can also be used as substitutes for muscles, with the advantages of simplicity and speed; IPMC's rely on ions to produce movement, but nanotubes are actuated directly by an applied current. On a sub-microscopic level, sheets of carbon are rolled up into tubes. When a current is run through them, the tubes contract like a natural muscle (Brabham et al., n.d.).

IPMCs and carbon nanotubes both belong to a class of artificial muscles called ElectroActive Polymers, which simply means electricity makes them work. These same kinds of devices may soon be used to restore motion to paralyzed facial muscles. With them, doctors will be able to restore function to an eyelid, or even bring mobility back to an entirely paralyzed face.

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